5. Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

Overview

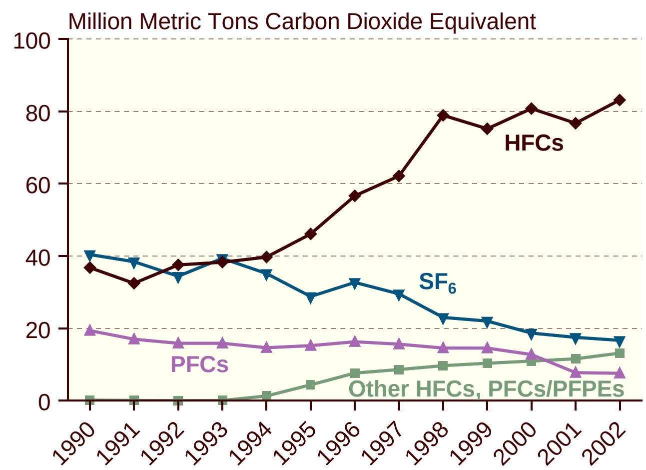
Total U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2002

Estimated 2002 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	120.6
Change Compared to 2001 (Million Metric Tons Carbon Dioxide Equivalent)	7.0
Change from 2001 *(Percent)*	*6.2%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	23.8
Change from 1990 *(Percent)*	*24.6%*

In addition to the three principal greenhouse gases (carbon dioxide, methane, and nitrous oxide), there are other gases that account for 1.8 percent of total U.S. greenhouse gas emissions when weighted by 100-year global warming potential (GWP).[75] The U.S. Environmental Protection Agency (EPA) estimates total emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) in 2002 at 120.6 million metric tons carbon dioxide equivalent—a 6.2-percent increase over 2001 emissions and a 24.6-percent increase over 1990 emissions. Table 29 summarizes U.S. emissions of HFCs, PFCs, and SF_6 from 1990 to 2002, and Table 30 shows the corresponding emissions in metric tons carbon dioxide equivalent.

In summary, revised EPA data for 1990-2001 and new estimates for 2002 show that emissions of HFCs have risen overall; annual emissions of PFCs declined overall from 1990 through 2000 and then dropped more significantly in 2001 and 2002; and SF_6 emissions have declined overall, falling to less than one-half their 1990 level by 2002 (Figure 5). In the case of HFCs, the overall increase in emissions reflects the use of HFCs as replacements for CFCs (chlorofluorocarbons), halons, and other ozone-depleting chemicals that are being phased out under the Montreal Protocol because they damage the Earth's stratospheric ozone layer.[76] The trend in HFC emissions is expected to accelerate in the next decade as HCFCs (hydrochlorofluorocarbons) used as interim substitutes for CFCs are also phased out under the provisions of the Copenhagen Amendments to the Montreal Protocol. PFC emissions from the aluminum industry have been falling since 1990; however, the decrease is partially offset by increases in PFC emissions from the semiconductor industry. Emissions of SF_6 have declined overall in the magnesium and utility sectors since 1990, despite an increase in use in the semiconductor industry.

Figure 5. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2002



Source: Estimates presented in this chapter.

[75]Preliminary data estimates received by EIA from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, August 2003. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the Intergovernmental Panel on Climate Change (IPCC) in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

[76]In previous years, this chapter included emissions estimates and accompanying discussions for a variety of ozone-depleting substances, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and bromofluorocarbons (halons) and criteria pollutants, such as carbon monoxide (CO), nitrogen oxides (NO_x), and nonmethane volatile organic compounds (NMVOCs), which have indirect effects on climate through their effects on atmospheric concentrations of greenhouse gases. Although no longer included in the main body of this report, emissions estimates for ozone-depleting substances and criteria pollutants are included in Energy Information Administration, *Documentation: Emissions of Greenhouse Gases in the United States 2002* (to be published).

The Intergovernmental Panel on Climate Change (IPCC) defines three classes of "other gases" to be included in estimating emissions: HFCs, PFCs, and SF_6. This chapter describes emissions sources and gives emissions estimates for these engineered chemicals, which occur on a very limited basis in nature.[77] Although they are much more potent when measured by their high GWPs than are the principal greenhouse gases, they are emitted in such small quantities that their overall impact is currently small.

The small quantities of HFCs, PFCs, and SF_6 that are emitted have disproportionate effects on overall emissions because of their large GWPs. PFCs and SF_6 have particularly high GWPs because of their scarcity, stability, strong infrared absorption in the atmosphere, and long atmospheric lifetimes.[78] SF_6 is the most potent of the greenhouse gases, with a GWP of 22,200. PFCs, with atmospheric lifetimes in the thousands of years, have GWPs in the range of 7,000 to 9,000. HFC-23 is the most potent greenhouse gas of the HFCs, with a GWP of 12,000, while other HFCs have GWPs in the range of 100 to 10,000.[79]

The emissions estimates in Table 29 are taken from data supplied by the EPA's Office of Air and Radiation.[80] The estimates in Table 30 are based on data provided by the EPA's Office of Air and Radiation in units of native gas (thousand metric tons), which were converted to carbon dioxide equivalent units by EIA, using GWP values from the IPCC's 2001 Third Assessment Report. The 2002 preliminary estimates were developed by the EPA and provided to EIA. They include some revisions to the historical emissions estimates, based on recent runs of the EPA's Vintaging Model (see boxes on pages 65 and 66). The revisions are reflected in the emissions estimates presented in this chapter.

Hydrofluorocarbons (HFCs)

Since 1990, HFC emissions have accounted for a growing share (68.9 percent in 2002) of total carbon dioxide equivalent emissions of HFCs, PFCs, and SF_6 combined. The EPA estimates U.S. emissions of all HFCs in 2002 at 83.1 million metric tons carbon dioxide equivalent, an 8.4-percent increase from 2001 emissions and a 126.0-percent increase from 1990.[81] The largest portion of HFC emissions, 75.4 percent, is attributed to their use as replacements for ozone-depleting substances, which has increased 84-fold since 1990.

U.S. Emissions of Hydrofluorocarbons, 1990-2002

Estimated 2002 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	83.1
Change Compared to 2001 (Million Metric Tons Carbon Dioxide Equivalent)	6.4
Change from 2001 *(Percent)*	*8.4%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	46.3
Change from 1990 *(Percent)*	*126.0%*

HFCs are compounds containing carbon, hydrogen, and fluorine. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases. HFCs are used in many applications, such as solvents, domestic and commercial refrigerants, firefighting agents, propellants for pharmaceutical and industrial aerosols, foam blowing agents, and in blends for air conditioning refrigerants.

The market for HFCs is expanding as CFCs and other ozone-depleting substances are being phased out under the Montreal Protocol and the Clean Air Act. HFCs have been introduced into the market to fill the void in many key applications. For example, HFCs are used in fire protection applications to replace Halon 1301 and Halon 1211, which are no longer being produced in the United States.[82] HCFCs, now interim replacements for CFCs, will also be phased out. For example, HCFC-141b and HCFC-142b, which are used as blowing agents in insulation foams, will be replaced by HFCs for some uses.[83]

[77]See Chapter 1, Table 1. Naturally occurring (pre-industrial) emissions of perfluoromethane (CF_4) were 40 parts per trillion. Their concentration had doubled by 1998.

[78]See discussion of relative forcing effects of gases in Chapter 1.

[79]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

[80]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

[81]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

[82]European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/others/firefighting/main_appli/main.htm.

[83]European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/insulation/main_appli/main.htm.

EPA Revises Emissions Estimation Methodology

The primary source for the emission estimates presented in this chapter is data obtained from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, which also prepares an annual inventory of greenhouse gas emissions.[a] The data supporting the EPA inventory include emissions estimates through 2002, incorporating a number of revisions to the estimates of HFC, PFC, and SF_6 emissions for 2001 and earlier years. Those changes are reflected in the estimates presented in this chapter.

The changes to the historical emission estimates are the result of revisions to the data and estimation methodologies used by the EPA:

- *Electrical Transmission and Distribution.* The primary change in the methodology for calculating emissions from electrical transmission and distribution is an increase in the assumed emission rate from equipment manufacturers. Previously, the emission rate was assumed to be 3 percent of the SF_6 charged into new equipment. The revised 2001 estimate bases the quantity of SF_6 charged into new equipment on statistics compiled by the National Electrical Manufacturers Association. The revised 10-percent emission rate is the average of the "ideal" and "realistic" manufacturing emission rates (4 percent and 17 percent, respectively), as identified in a paper prepared under the auspices of the International Council on Large Electric Systems (CIGRE).[b] This revision resulted in an average annual increase of 3.7 percent in SF_6 emissions for the period 1990 through 2000.
- *Magnesium Production and Processing.* The emissions estimates in this report were revised to reflect new activity data for magnesium production and processing, which affected the emission factor for die casting. The new, lower emission factor was adjusted to account for lower emission rates reported by participants in EPA's SF_6 Emission Reduction Partnership for the Magnesium Industry, including nearly 100 percent of all die casting operations in the United States. The combination of these changes and the methodological revision described above resulted in an average annual decrease of about 1.9 percent in SF_6 emissions for the period 1990 through 2000.
- *Substitution of Ozone-Depleting Substances.* The EPA updated assumptions for its Vintaging Model in the fire-extinguishing sector. These changes resulted in an average annual decrease of 0.7 percent in HFC and PFC emissions for the period 1994 through 2000.
- *Aluminum Production.* In cooperation with the EPA's Voluntary Aluminum Industrial Partnership program, participants provided additional smelter-specific information on aluminum production and the frequency and duration of anode effects. The new information resulted in a decrease of 0.3 percent in PFC emissions for 2000.

[a]The information presented in this text box was obtained from U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

[b]P. O'Connell, F. Heil, J. Henriot, G. Mauthe, H. Morrison, L. Neimeyer, M. Pittroff, R. Probst, and J.P. Tailebois, *SF_6 in the Electric Industry, Status 2000* (CIGRE, February 2002).

Trifluoromethane (HFC-23)

The EPA estimates 2002 emissions of HFC-23 at 1,754 metric tons of gas.[84] Annual emissions have fluctuated since 1990, showing an overall decline of 41.6 percent by 2002. Although emissions of HFC-23 are relatively small, its high GWP (12,000)[85] gives it a substantial potential climatic effect. Nearly all HFC-23 emissions (96.4 percent) are created as a byproduct in the production of chlorodifluoromethane (HCFC-22) and generally are vented to the atmosphere. In some cases the HFC-23 is captured for use in a limited number of applications. While production of HCFC-22 continues to grow, emissions of HFC-23 from this source have declined, because the emission rate of HFC-23 (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) has declined significantly since 1990.[86]

HCFC-22 is used as a blowing agent component for polyurethane foams and extruded polystyrene foams, and in the refrigerant market for stationary refrigeration and air conditioning (including chillers, room and

[84]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

[85]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

[86]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

The EPA Vintaging Model: Estimation Methods and Uncertainty

The U.S. Environmental Protection Agency (EPA) uses a detailed Vintaging Model for equipment and products containing ozone-depleting substances (ODS) and ODS substitutes to estimate actual versus potential emissions of various ODS substitutes, including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The model estimates the quantities of equipment and products sold each year that contain ODS and ODS substitutes, and the amounts of chemicals required for their manufacture and/or maintenance over time. Emissions from more than 40 different end uses are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as it leaks over time.

For most products (refrigerators, air conditioners, fire extinguishers, etc.), emissions calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses plus emissions from manufacture; and disposal emissions, which occur when the equipment is discarded. By aggregating the data over different end uses, the model produces estimates of annual use and emissions of each compound.[a]

The EPA is consistently making improvements to the model to use more accurate data from the industries and to reduce uncertainty. The level of detail incorporated in the EPA Vintaging Model is higher than that of the default methodology used by the Intergovernmental Panel on Climate Change, reducing the uncertainty of model inputs, such as equipment characteristics and sales figures.

[a]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

household (central) air conditioners, and dehumidifiers). The EPA administers a voluntary program with HCFC-22 producers to reduce HFC-23 emissions, which has helped to offset the rising demand for HCFC-22 in the short term. In the long term, domestic production of HCFC-22 for non-feedstock uses will be phased out by 2020 under the U.S. Clean Air Act, pursuant to U.S. agreements under the Copenhagen Amendments to the Montreal Protocol. However, its production for use as a feedstock in the production of other chemicals (fluorinated polymers) will be allowed to continue indefinitely and is anticipated to grow.[87]

Tetrafluoroethane (HFC-134a)

According to EPA estimates, emissions of HFC-134a, which has a GWP of 1,300,[88] have grown from 564 metric tons in 1990 to 33,963 metric tons in 2002.[89] HFC-134a accounts for the largest share of all HFC emissions (53.1 percent in terms of carbon dioxide equivalent), and the single largest share of any one gas for all HFC, PFC, and SF_6 emissions combined (36.6 percent). The 2002 estimate is 7.6 percent higher than that for 2001. Emissions of HFC-134a have increased more than 59-fold since 1990, more rapidly than emissions of any other single greenhouse gas.

Since 1994, HFC-134a has been the transportation industry standard for replacing CFCs in air conditioners for passenger cars, trucks, trains, and buses, because it is nonflammable and has low toxicity. It is also used for domestic refrigeration and freezing, as a propellant for industrial and pharmaceutical aerosols, as a solvent, and as a blowing agent for extruded polystyrene foams.

HFC-134a is also used in refrigerant blends (e.g. R-404A) in most new commercial refrigeration equipment built in the United States and in commercial chillers, but leakage from these sources is much less than from automotive air conditioners. Leakage occurs primarily during servicing of the units rather than during normal operation. Short-term uses of HFC-134a, on the other hand, are becoming an important source of emissions. Such uses include aerosols and open-cell foam blowing, which are denoted as short-term uses because most of the HFC-134a used will be emitted to the atmosphere within a short period of time.

HFCs make attractive solvents because of their nonflammability, thermal and chemical stability, excellent dielectric properties, high material compatibility, low surface tension and viscosity, and high liquid density. HFC-134a, in particular, is used in special extraction processes to produce important natural active

[87]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

[88]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

[89]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

pharmaceuticals, such as taxol for breast cancer treatment, nutraceuticals, flavors, and fragrances.[90] According to the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), worldwide sales of HFC-134a jumped almost fourfold between 1992 and 1993, doubled again in 1994, and continued growing steadily to 131,969 metric tons of gas in 2001.[91]

A number of HFC-134a producers are undertaking modest capacity expansion projects, including DuPont, INEOSFluor (formerly ICI Klea), and Honeywell (formerly AlliedSignal). More significant additions of new capacity are likely to be needed, however, given that capacity is increasing by only 2 to 3 percent per year, while global demand is growing by 10 percent.[92] Anticipating and planning for this growth has proven to be a difficult challenge for producers, who must manage as best they can an unprecedented transition from an established product (CFC-12), which is being phased out under a global treaty, to a new product (HFC-134a).

Other HFCs

Other hydrofluorocarbons with considerable radiative forcing potential include HFC-125, HFC-143a, and HFC-236fa, with 100-year GWPs of 3,400, 4,300, and 9,400, respectively.[93] The EPA estimates emissions of HFC-125 (pentafluoroethane) at 236 metric tons of gas in 1992, increasing to 2,283 metric tons in 2002.[94] The estimate for 2002 is 22.1 percent higher than the estimate for 2001. HFC-125 is used in the blend R-410A, which is designed to replace HCFC-22 as the refrigerant of choice for stationary commercial refrigeration and air conditioning applications, as well as in the blends R-404A and R-507A. Some manufacturers have already introduced air conditioners that use R-410A, but as yet the product has captured only a small percentage of the market. As the phaseout of HCFC-22 begins to gain momentum, producers expect a rapid increase in the demand for R-410A.[95] HFC-125 can also be used as a firefighting agent.

The EPA estimates 1993 emissions of HFC-143a (trifluoroethane) at 12 metric tons of gas, increasing to 1,413 metric tons in 2002.[96] The estimate for 2002 is 23.8 percent higher than the estimate for 2001. HFC-143a is a halocarbon used in blends for commercial refrigeration and air conditioning, such as R-404A and R-507A. HFC-143a, like other HFCs, is used as a substitute because it contains neither chlorine nor bromine and will not emit ozone-depleting halogen radicals into the stratosphere. Like other halocarbons, HFC-143a does make a positive contribution to atmospheric warming; however, the GWPs of R-404A and R-507A are lower than those of the gases it replaces, such as CFC-12.

The EPA estimates 1997 emissions of HFC-236fa (hexafluoropropane) at 15 metric tons of gas, increasing to 435 metric tons in 2002.[97] The estimate for 2002 is 17.7 percent higher than the estimate for 2001. HFC-236fa is also used as a refrigerant, in particular by the U.S. Navy for shipboard applications.[98] In another application, HFC-236fa is used as a firefighting agent.

There is a group of other HFCs and PFCs/PFPEs for which the EPA withholds individual emissions data, because the data are considered confidential and could compromise business practices. This group includes HFC-152a, HFC-227ea, HFC-245fa, and HFC-4310mee, with 100-year GWPs of 120, 3,500, 950, and 1,500, respectively.[99] The EPA estimates total emissions of this group of "other HFCs" at 13.2 million metric tons carbon dioxide equivalent in 2002, representing 10.9 percent of all emissions of HFCs, PFCs, and SF_6 reported.[100] Emissions of these HFCs are small but growing rapidly, as they continue to find applications as substitutes for CFCs and HCFCs. Emissions of "other HFCs" have increased by 13.5 percent since 2001 and by more than 72-fold since 1990.

Other HFCs and HFC blends are also likely to gain market share as a result of the phaseout of CFCs and HCFCs, because no single product is suited for all applications. For example, each potential replacement product has an

[90] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/solvents/main_appli/main.htm.

[91] Alternative Fluorocarbons Environmental Acceptability Study, Production, Sales and Atmospheric Release, web site www.afeas.org/prodsales_download.html.

[92] J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

[93] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

[94] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

[95] J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

[96] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

[97] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

[98] E-mail correspondence with the Office of Policy, U.S. Department of Energy, October 18, 2000.

[99] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

[100] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

optimal operating temperature range; hence, the refrigerant best suited for use in ice cream freezers will differ from the best choice for milk coolers.[101]

In addition to replacing HCFC-22 in stationary air conditioning and refrigeration applications, other HFCs are expected to gain new markets as foam blowing agents. CFCs have already been phased out of this market, having been replaced by HCFCs (primarily HCFC-141b). Among the potential replacements, HFC-245fa (pentafluoropropane) appears to be the strongest contender.[102] Demand for Honeywell's insulating foam agent Enovate™ 3000 (HFC-245fa) is so strong that the company is building a new plant in Geismar, Louisiana, which began commercial operation in early August 2002.[103] Honeywell is also developing blends that combine HFC-245fa with other materials to enhance its cost/performance ratio. For some applications, nonfluorochemical alternatives (e.g., hydrocarbons) have been identified.[104]

Perfluorocarbons (PFCs)

U.S. Emissions of Perfluorocarbons, 1990-2002

Estimated 2002 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	7.6
Change Compared to 2001 (Million Metric Tons Carbon Dioxide Equivalent)	-0.2
Change from 2001 *(Percent)*	*-2.2%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-11.8
Change from 1990 *(Percent)*	*-60.8%*

The EPA estimates 2002 emissions of PFCs at 7.6 million metric tons carbon dioxide equivalent, accounting for 6.3 percent of all emissions of HFCs, PFCs, and SF_6 combined. The estimate for 2002 is 2.2 percent lower than the estimate for 2001 and 60.8 percent lower than 1990 emissions (Table 30).[105] The overall decrease is the result of improvements in the aluminum industry, which creates PFCs as byproducts, as well as decreases in domestic aluminum production; a small increase in PFC emissions is seen in industrial applications, such as in semiconductor manufacturing.

PFCs are compounds composed of carbon and fluorine. PFC emissions are not regulated, although their high GWPs (5,700 for perfluoromethane [CF_4] and 11,900 for perfluoroethane [C_2F_6])[106] have drawn attention. PFCs are also characterized by long atmospheric lifetimes (up to 50,000 years); hence, unlike most HFCs, they are essentially permanent additions to the atmosphere.

The principal quantifiable source of PFCs is as a byproduct of aluminum smelting created during periods of process inefficiency and disruption. The amount created depends on the frequency and duration of the events. The EPA estimates U.S. emissions from aluminum production at 531 metric tons of perfluoromethane and 56 metric tons of perfluoroethane in 2002.[107] Reductions in primary aluminum production and efficiency improvements to reduce anode effects leading to process inefficiency have contributed to reductions in emissions of perfluoromethane and perfluoroethane from this source by 78.2 percent and 77.3 percent, respectively, since 1990.

Aluminum smelting companies that participate in EPA's Voluntary Aluminum Industry Partnership (VAIP) program have achieved many efficiency improvements through voluntary actions. Reductions in primary aluminum production have also played a role in reducing PFC emissions. According to data from the U.S. Geological Survey, domestic primary aluminum production decreased significantly in 2002 as a result of cutbacks in smelter production, which in turn were caused by increased energy costs in various parts of the country.

Another source of PFC emissions is semiconductor manufacturing. For 2002, the EPA estimates emissions of perfluoromethane and perfluoroethane from semiconductor manufacturing at 175 metric tons and 244 metric tons of gas, respectively.[108] Both estimates reflect the rapid growth of the semiconductor industry in the

[101]C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).
[102]C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).
[103]Honeywell, "Honeywell Prepares for First Shipments of Commercially Produced Enovate™ 3000 Blowing Agent," Press Release (August 22, 2002), web site www.enovate3000.com/pdfs/PressRelease8-16.pdf.
[104]J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).
[105]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.
[106]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.
[107]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.
[108]Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

1990s, which resulted in increases of 52.2 percent and 52.6 percent in emissions of perfluoromethane and perfluoroethane, respectively, since 1990. Perfluoromethane and perfluoroethane are used as plasma etchants and cleaning agents in semiconductor manufacturing; some of the gas used in those processes does not react with the materials and, unless abated, is emitted to the atmosphere. A variety of other perfluorinated compounds are used in the semiconductor industry, including perfluoropropane (C_3F_8, with a GWP of 8,600), perfluorobutane (C_4F_{10}, GWP 8,600), perfluorohexane (C_6F_{14}, GWP 9,000), and nitrogen trifluoride (NF_3).[109] Although continued expansion of the worldwide semiconductor market may lead to increased PFC use and emissions, emissions of PFCs from this source have been falling since their peak in 1999 as a result of drops in semiconductor production (and silicon consumption) and voluntary industry efforts to curb emissions through new methods, such as process optimization.[110]

Sulfur Hexafluoride (SF_6)

U.S. Emissions of Sulfur Hexafluoride, 1990-2002

Estimated 2002 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	16.7
Change Compared to 2001 (Million Metric Tons Carbon Dioxide Equivalent)	-0.8
Change from 2001 *(Percent)*	*-4.7%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-23.7
Change from 1990 *(Percent)*	*-58.7%*

The EPA estimates 2002 emissions of SF_6 at 752 metric tons of gas, accounting for 13.8 percent of all HFC, PFC, and SF_6 emissions combined in 2002.[111] The estimate for 2002 is 58.7 percent lower than the estimate for 1990. The decrease is the result of industry efforts to reduce emissions from electrical power systems, the rising cost of SF_6, and the closure of a major U.S. magnesium production facility. In contrast, emissions of SF_6 from uses in the semiconductor manufacturing industry have increased overall by 30.5 percent since 1990.

SF_6 is used primarily in electrical applications and magnesium metal casting processes. SF_6 is an excellent dielectric gas for high-voltage applications, because it is chemically inert, gaseous at low temperatures, nonflammable, nontoxic, and noncorrosive.[112] In electrical transmission and distribution systems, SF_6 acts as an insulator and arc interrupter for circuit breakers, switch gear, and other electrical equipment; however, it can escape through seals, especially in older equipment. Emissions also occur during equipment installation, servicing, and disposal.[113]

Other applications that produce SF_6 emissions include magnesium metal casting processes that employ SF_6 to replace toxic and corrosive materials, such as salt fluxes and sulfur dioxide (SO_2). Another important use of SF_6 is as a cover gas during magnesium production and processing to prevent excessive oxidation of molten magnesium in the presence of air. Pre-treating aluminum melt with SF_6 (or an inert gas mixture) prevents porosity and therefore weakening of the metal. It also removes oxides and solid impurities. In addition, mixtures of SF_6 and O_2 are used as feed gases for plasma etching of semiconductor devices.[114] Because of its extremely low atmospheric concentration, SF_6 is also useful as an atmospheric tracer gas for a variety of experimental purposes. Other minor applications include leak detection, loud speakers, lasers, and as a cover gas or fluxing and degassing agent for specialized casting operations in the aluminum industry.[115]

[109] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.

[110] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), Annex J, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG EmissionsUSEmissionsInventory2003.html.

[111] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, August 2003.

[112] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?chfamilies/SF6/prod_main/prod.htm.

[113] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2003.html.

[114] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/electri_appli/main_appli/main.htm.

[115] Historically, emissions of SF_6 from the aluminum industry have been omitted from global estimates, because any emissions are expected to be insignificant. The EPA does not estimate emissions from this source due to uncertainties about the quantities used and the amounts destroyed in the applications.

In compiling its estimates, the EPA receives data from participants in the SF_6 Emission Reduction Partnership for Electric Power Systems and the SF_6 Emissions Reduction Partnership for the Magnesium Industry. The uncertainty associated with SF_6 emissions in the electric power industry is noteworthy, because the data reported cover only 1999, 2000, and 2001, and a model was necessary to "backcast" emissions for 1990 to 1998, as well as for those utilities not reporting to the program. A major model assumption made regarding magnesium processing, that SF_6 neither reacts nor decomposes, adds an element of uncertainty to the estimates.[116]

[116]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2003.html.

Table 29. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2002
(Thousand Metric Tons of Gas)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	P2002
Hydrofluorocarbons													
HFC-23	3.0	2.6	3.0	2.7	2.7	2.3	2.7	2.6	3.5	2.7	2.6	1.7	1.8
HFC-125	*	*	0.2	0.5	0.3	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.3
HFC-134a	0.6	0.6	0.6	2.9	4.5	12.2	16.2	20.2	23.1	26.1	28.9	31.6	34.0
HFC-143a	*	*	*	*	0.1	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.4
HFC-236fa	*	*	*	*	*	*	*	*	0.1	0.2	0.3	0.4	0.4
Perfluorocarbons													
CF_4	2.6	2.2	2.1	2.0	1.8	1.8	1.9	1.8	1.5	1.5	1.4	0.8	0.7
C_2F_6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.3	0.3
C_4F_{10}	*	*	*	*	*	*	*	*	*	*	*	*	*
PFCs/PFPEs	W	W	W	W	W	W	W	W	W	W	W	W	W
Other HFCs, PFCs/PFPEs	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Sulfur Hexafluoride	**1.8**	**1.7**	**1.6**	**1.8**	**1.6**	**1.3**	**1.5**	**1.3**	**1.0**	**1.0**	**0.8**	**0.8**	**0.8**

*Less than 50 metric tons of gas.
P = preliminary data. M = mixture of gases. W = withheld to avoid disclosure of confidential data.
Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, August 2003).

Table 30. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2002
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	P2002
Hydrofluorocarbons													
HFC-23	36.1	31.7	35.9	32.9	32.7	28.1	32.4	31.3	41.9	31.9	31.2	20.9	21.0
HFC-125	*	*	0.8	1.6	1.0	1.6	2.3	3.0	3.8	4.4	5.3	6.4	7.8
HFC-134a	0.7	0.7	0.8	3.8	5.8	15.9	21.1	26.2	30.0	33.9	37.6	41.0	44.2
HFC-143a	*	*	*	0.1	0.2	0.5	0.9	1.4	2.1	2.9	3.9	4.9	6.1
HFC-236fa	*	*	*	*	*	*	*	0.1	1.1	2.0	2.8	3.5	4.1
Total HFCs	**36.8**	**32.5**	**37.6**	**38.3**	**39.7**	**46.1**	**56.6**	**62.1**	**78.9**	**75.2**	**80.8**	**76.7**	**83.1**
Perfluorocarbons													
CF_4	14.5	12.6	11.7	11.4	10.2	10.3	11.0	10.0	8.7	8.6	7.9	4.3	4.0
C_2F_6	4.9	4.4	4.2	4.4	4.4	4.9	5.3	5.6	5.9	5.9	4.9	3.5	3.6
C_4F_{10}	*	*	*	*	*	*	*	*	*	*	*	*	*
Total PFCs	**19.4**	**17.0**	**15.9**	**15.9**	**14.7**	**15.2**	**16.3**	**15.6**	**14.6**	**14.6**	**12.8**	**7.8**	**7.6**
Other HFCs, PFCs/PFPEs	**0.2**	**0.1**	**0.0**	**0.1**	**1.3**	**4.4**	**7.7**	**8.6**	**9.7**	**10.4**	**11.0**	**11.6**	**13.2**
Sulfur Hexafluoride	**40.4**	**38.4**	**34.4**	**39.4**	**35.2**	**28.8**	**32.7**	**29.5**	**23.0**	**22.0**	**18.7**	**17.5**	**16.7**
Total Emissions	**96.8**	**88.0**	**87.9**	**93.6**	**90.9**	**94.6**	**113.3**	**116.0**	**126.2**	**122.1**	**123.2**	**113.6**	**120.6**

*Less than 0.05 million metric tons carbon dioxide equivalent.
P = preliminary data.
Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, August 2003).